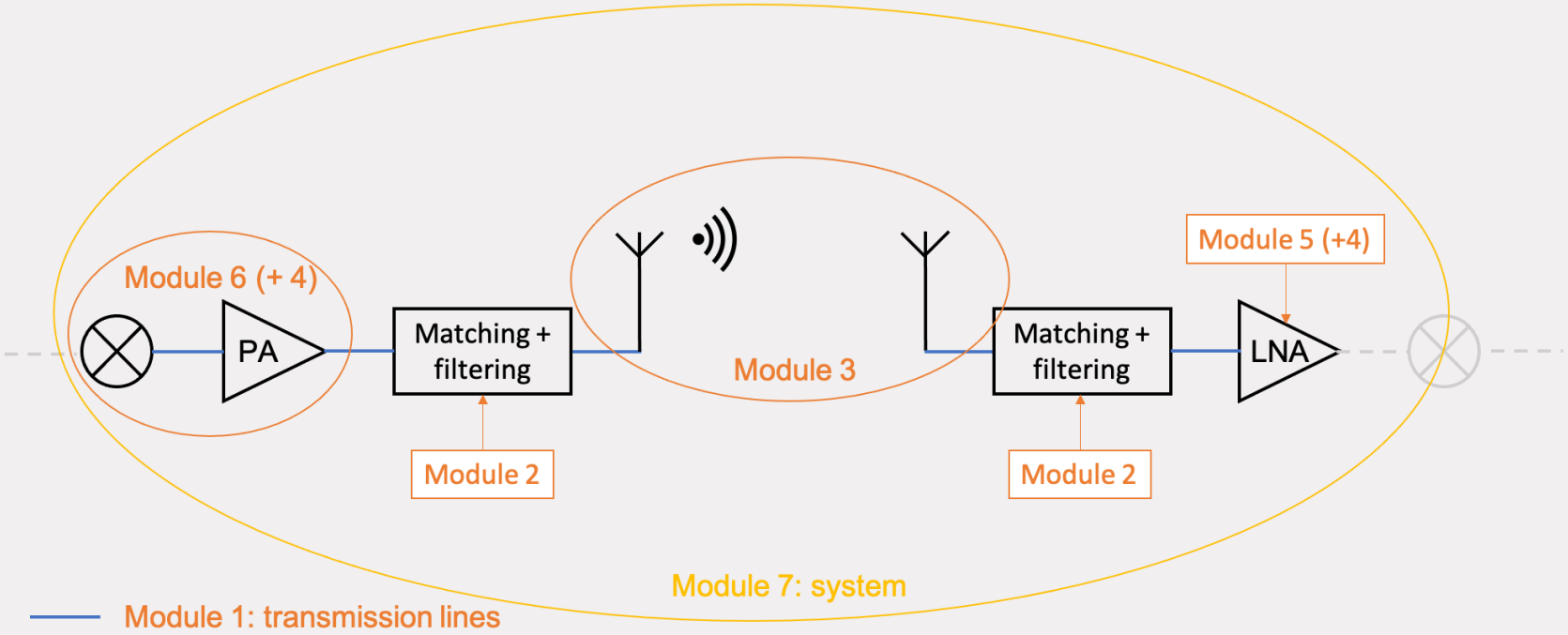
System Level Considerations

5XTC0 – Components in Wireless Technologies

Dr. Ulf Johannsen

Modules - Overview



Lecture overview

Aim of this lecture:

- Give a guideline for successful antenna (system) design

Flow:

- The Problem: Antenna Design for 5G New Radio
- The Solution: Systems Engineering – A Brief Introduction
- Applying SE practices to mm-Wave Antenna System Development
- Conclusions

The Problem of Antenna Integration at mm-Waves

Antenna Integration is a Consequence of Moving Up in Frequency:

Distance between antenna and electronics must be short:

- ~8 dBm @ 30GHz per amplifier for BiCMOS
- Noise Figure:

$$NF_{Sys} = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + \cdots$$

- Unit for measuring distances: λ (wavelength)!

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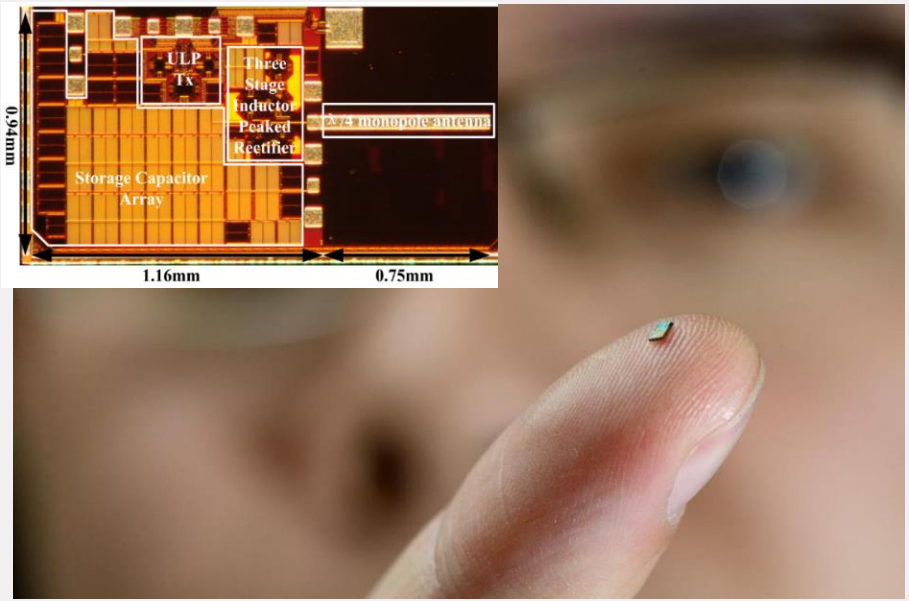
The Problem of Antenna Integration at mm-Waves

Keep distance between antenna and electronics well below one wavelength, i.e. 1-10mm!



The Problem of Antenna Integration at mm-Waves

So, why is this a problem?

Semiconductor processes and packaging technologies have been optimised for decades to support electronics:

- Highly doped substrates → lossy
- Flip-chip interconnects → chips mounted up-side-down on system PCB
- Moulding compounds optimised for heat dissipation and moisture blockage → lossy encapsulation materials + package resonances

The Problem of Antenna Integration at mm-Waves

Moreover, we need to overcome the free space path loss:

Physics

Limited

$$P_{Rx} = \left(\frac{\lambda}{4\pi R}\right)^2 G_{Rx} G_{Tx} P_{Tx}$$

Required

Maximise Antenna Gain!

→ Use of Phased Arrays!

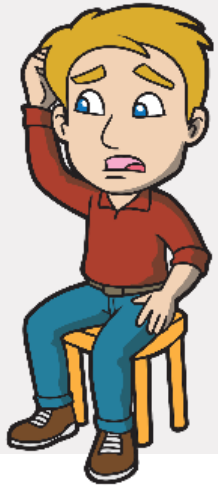
The Problem of Antenna Integration at mm-Waves

So, we actually need an antenna system, consisting of

- Antennas,
- Millimeter-wave electronics,
- Power supplies,
- Control circuitry,
- Feed-networks (RF signals and reference oscillators)…

For a successful design we need to consider

- Antenna requirements,
- Electromagnetic compatibility,
- Power consumption,
- Heat dissipation,
- Tolerances,
- Costs…



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The Solution: Systems Engineering – A Brief Introduction

IEEE Definition:

An interdisciplinary, collaborative approach that derives, evolves, and verifies a life-cycle balanced system solution which satisfies customer expectations and meets public acceptability.
(IEEE P1220, *Standard for Application and Management of the Systems Engineering Process*, [Final Draft], 26 September 1994.)

European Space Agency:

Systems engineering is the process of designing, developing and verifying a space system as an integrated system able to fulfil the objectives of a mission within acceptable technical and programmatic frames.
(http://www.esa.int/Our_Activities/Space_Engineering_Technology/Systems_Engineering_incl._cost_engineering, July 2018)

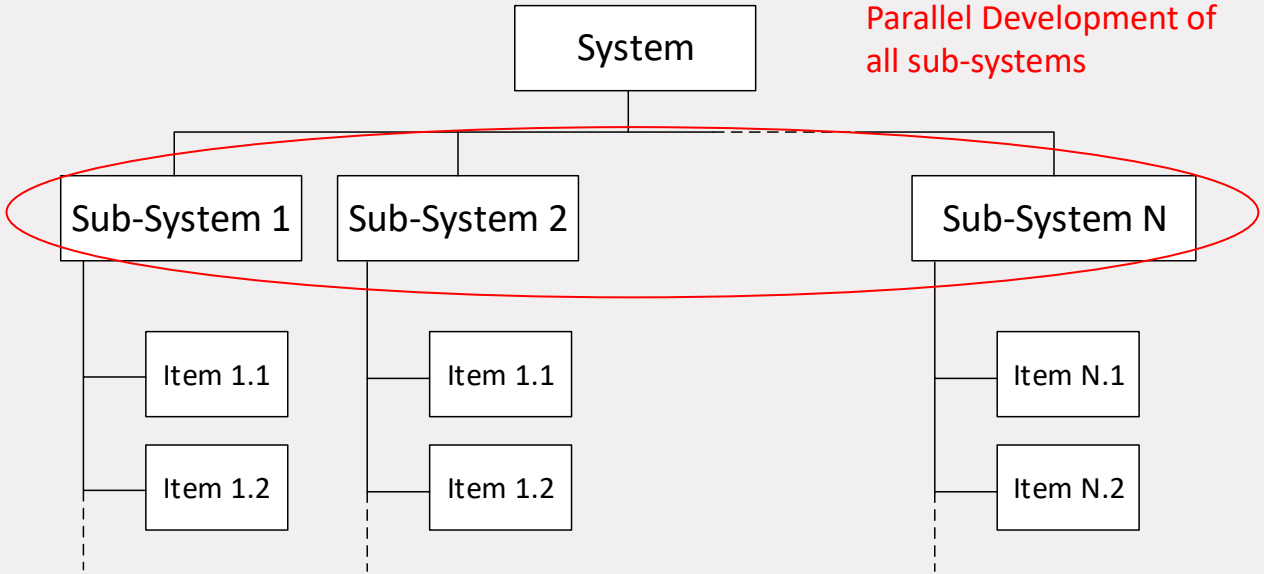
Systems engineering consists of two significant disciplines:

1. the technical knowledge domain
2. systems engineering management

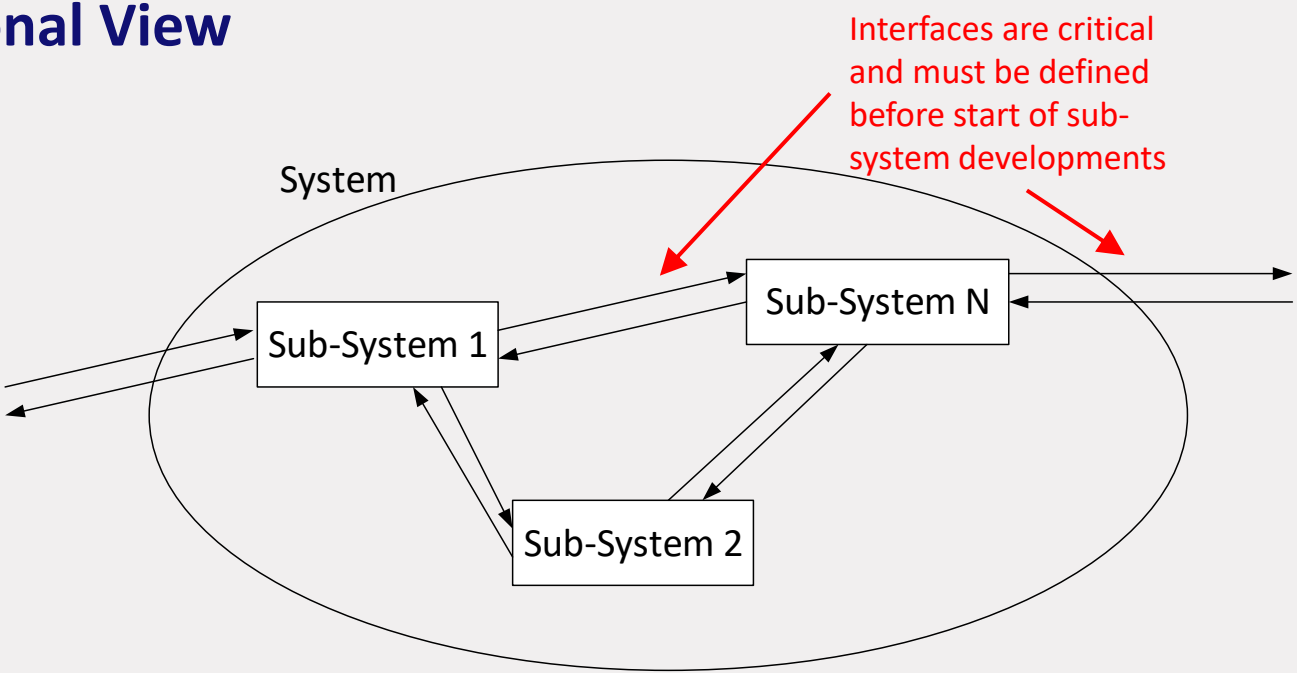
(DEFENSE ACQUISITION UNIV FT BELVOIR, VA, "System Engineering Fundamentals," *Defense Technical Information Center (US DoD),* 2001)

A good book: A. Kossiakoff et al., "Systems Engineering – Principles and Practice," 2nd Edition, John Wiley & Sons Inc., 2011

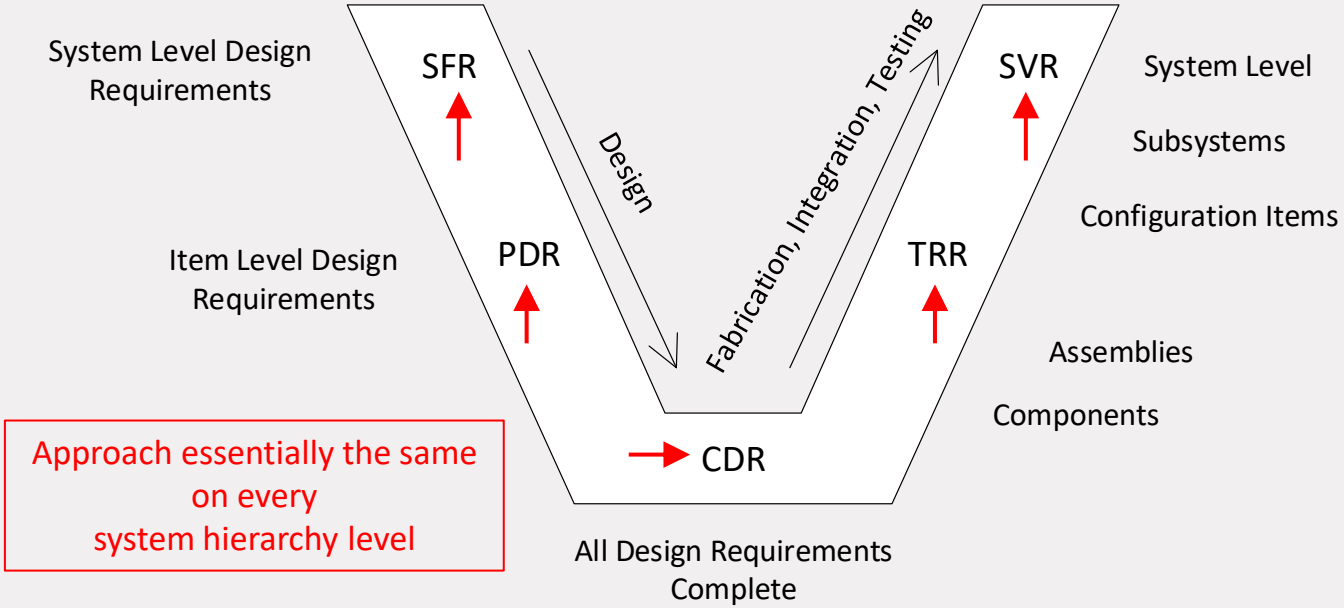
System Decomposition – Hierarchical View



System Decomposition – Functional View



Systems Engineering and Verification[1]



[1] DEFENSE ACQUISITION UNIV FT BELVOIR, VA, "System Engineering Fundamentals," *Defense Technical Information Center* , 2001

Lecture overview

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Applying SE Practices to mm-Wave Antenna System Development

Design Requirements and System Architecture

System Detailed Design: “The Fun Stuff”

Validation: Antenna System Characterisation

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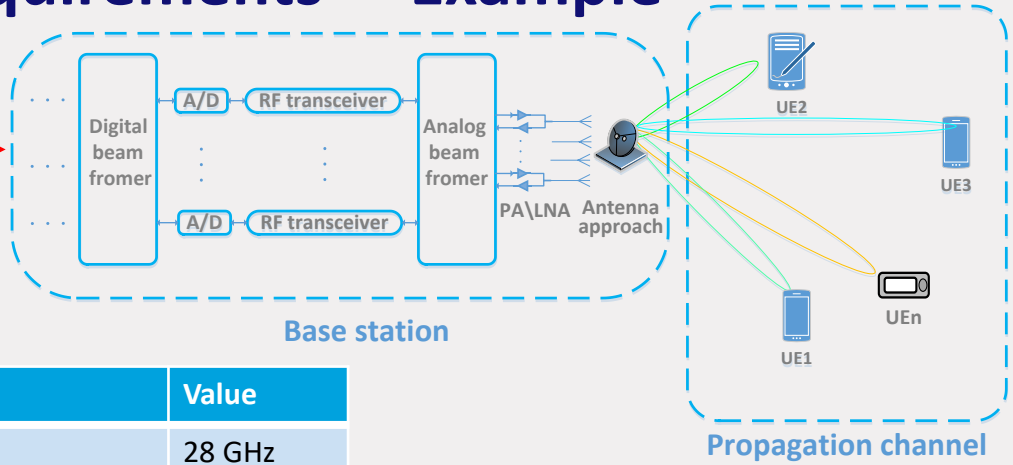
System Level Requirements – Example

High-Level System Diagram

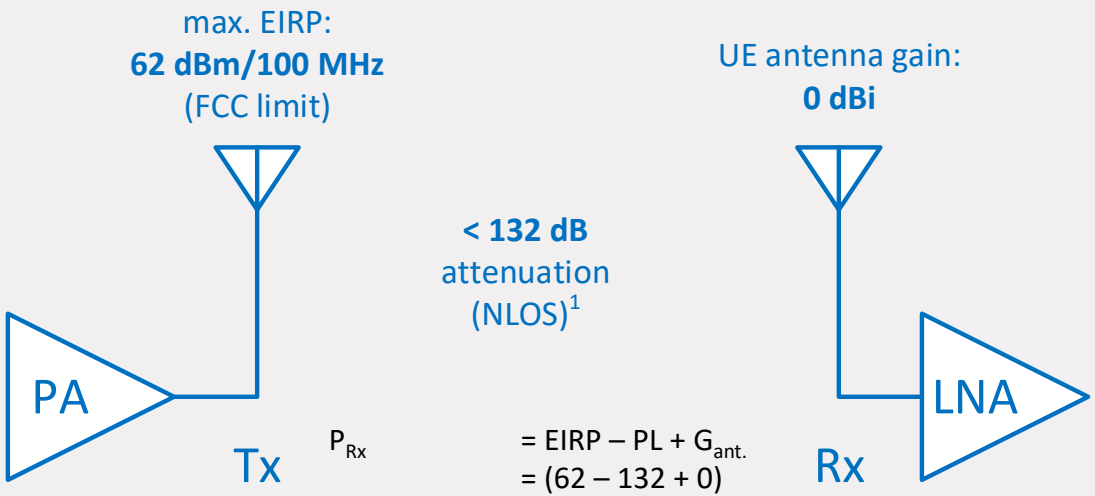


Parameter	Value
Frequency	28 GHz
Bandwidth	3 GHz
Polarisation	Dual-Linear
Average PA output power (chips supplied)	8 dBm
Communication distance (max. cell size)	< 150 m
Average Data Rate per User	1 Gbps

System-Level Requirements

System Level Architecting – Concept Exploration

Feasibility Study



* FCC "Fact Sheet: Spectrum Frontiers Proposal to Identify, Open Up Vast Amounts of New High- Band Spectrum for Next Generation (5G) Wireless Broadband," June 2016.

[1] Based on "White paper: 5G Channel Model for bands up to 100 GHz (Annex)," Dept. of Computer Science, Michigan State University, September 2016

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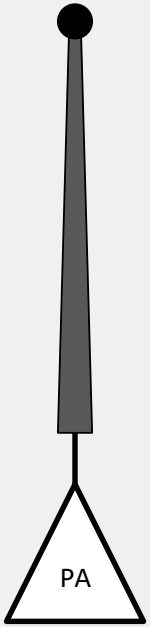
System Level Architecting – Concept Exploration

How to achieve 62 dBm EIRP?

Option 1:



0 dBi

- Only 8dBm availabe
- No (massive) MIMO

P_{Tx} > 1500W

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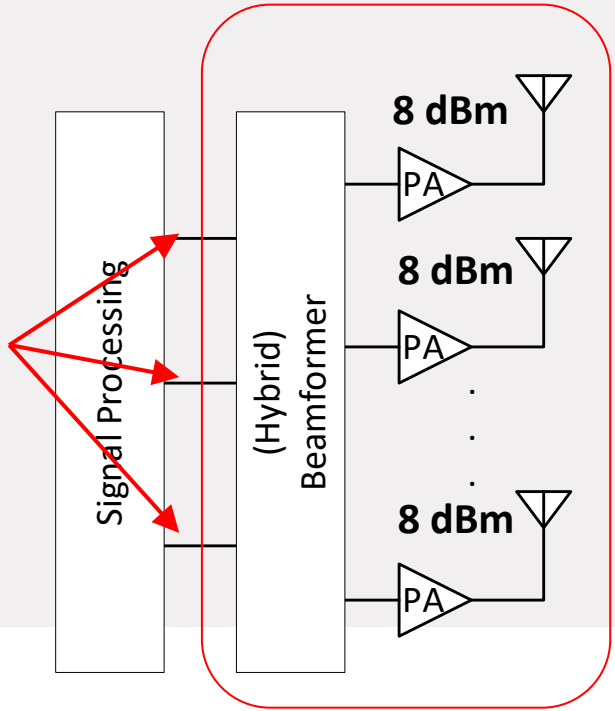
System Level Architecting – Concept Exploration

How to achieve 62 dBm EIRP?

Option 2:



Interfaces to be well defined!

N ≈ 250 elements (6 dBi)

➔ 32 dBm Tx Power

Our job!

Applying SE Practices to mm-Wave Antenna System Development

Design Requirements and System Architecture

System Detailed Design: “The Fun Stuff”

Validation: Antenna System Characterisation

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Technology Choice

How to successfully design an antenna that can actually be realised (manufactured)?

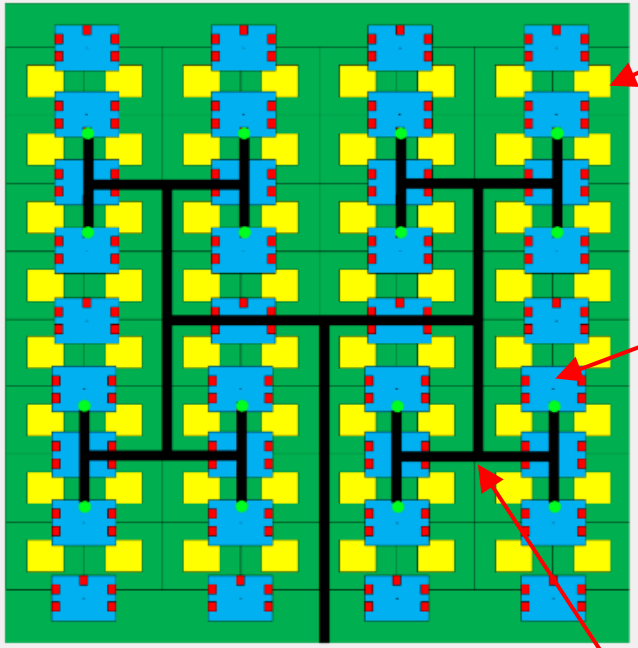
You need to understand the technology you want to use!

- Electrical parameters (conductivity, permittivity, loss tangent)
- Mechanical parameters (e.g. Young's modulus)

➔Design rules

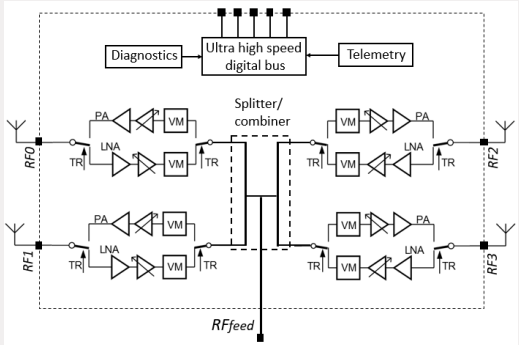
- Manufacturing process

Array Design Architecture



256-element array (4x 64-element patch antenna array)

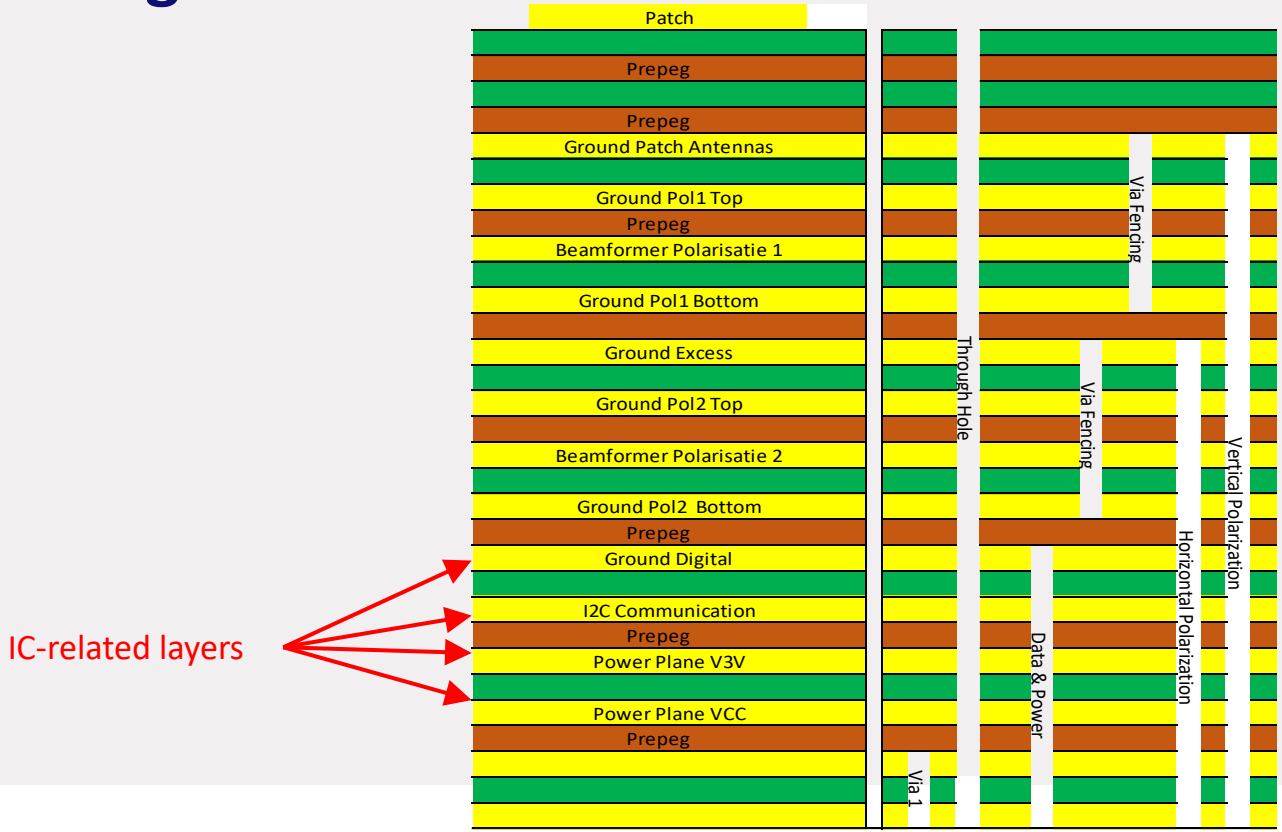
Use commercial off-the-shelf (COTS) analogue beamformer chip from NXP



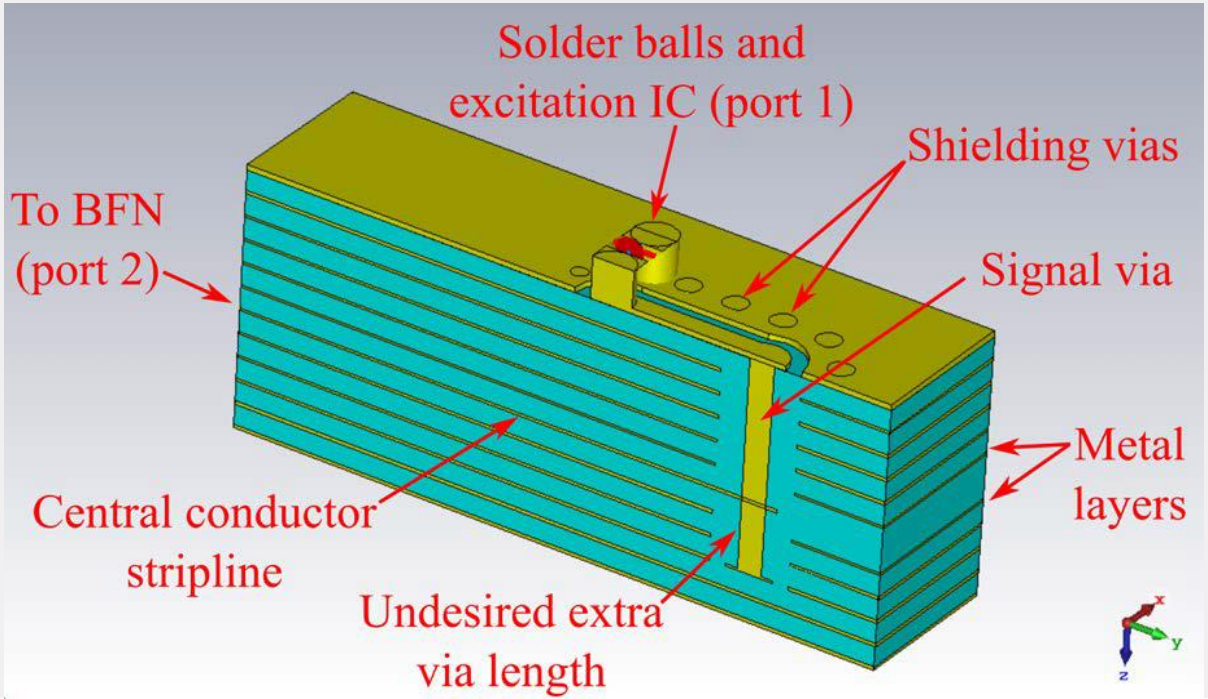
Interface 28 GHz signal via one SMPM connector per 64-element array

Passive feed-network

Array Design Architecture



Coping with manufacturability: Matching

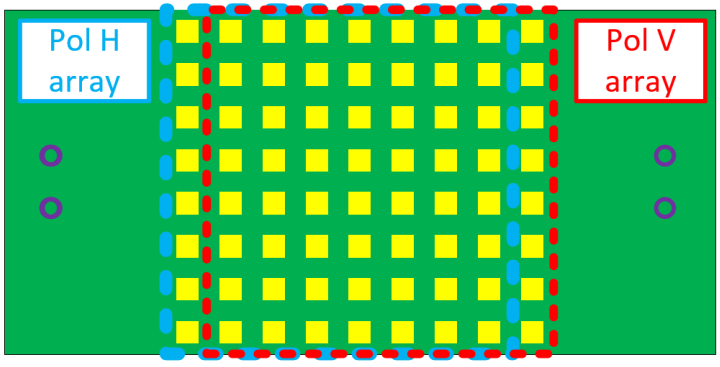


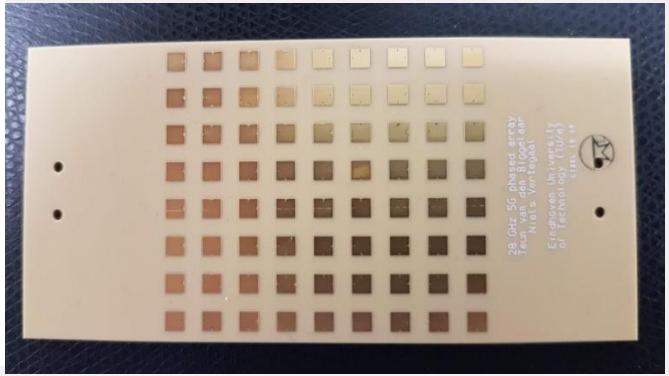
The Actual Antenna Engineering

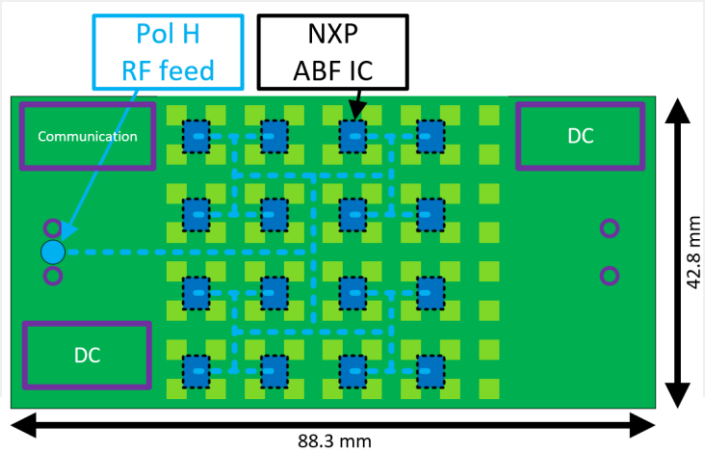
Things to keep in mind during the design process:

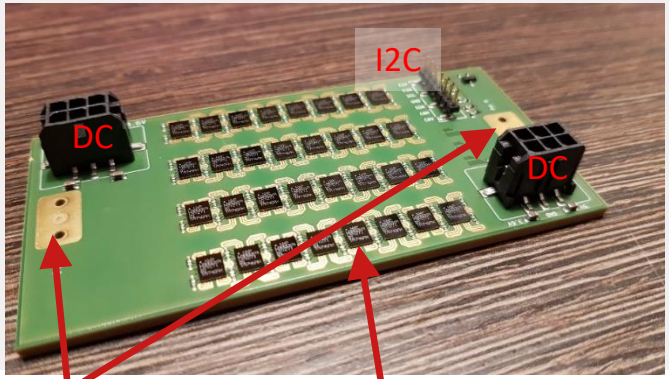
- Antenna requirements
  - impedance, gain, scan range etc.
  - Calibration requirements (!)
- Manufacturability
  - Talk to the manufacturer early in the design phase, as not everything that works in your design tool also works in reality!
  - Take fabrication tolerances into account and test your design for extreme cases
- Testability
  - Make sure that you design your antenna such that it can be characterised in your setup
  - Make sure you can characterise critical parts of your design independently

Outcome of this Design Example



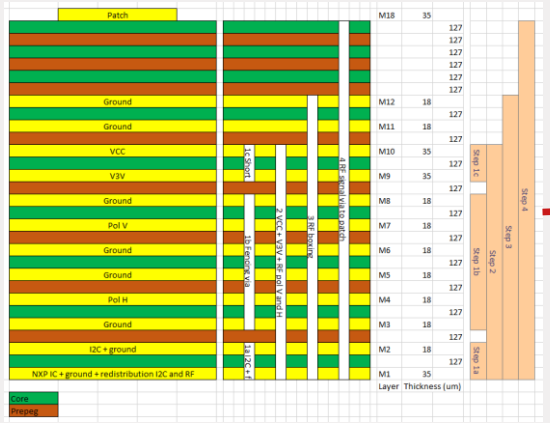


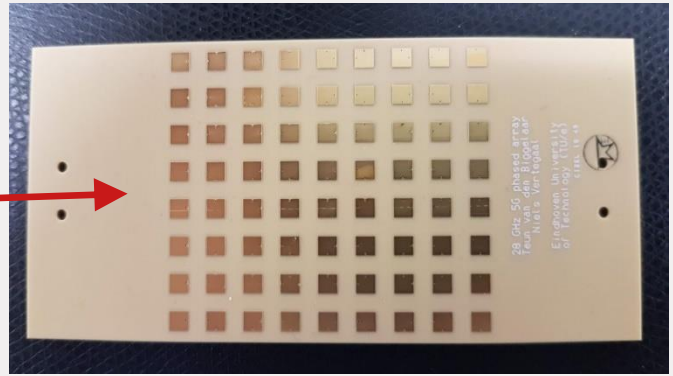


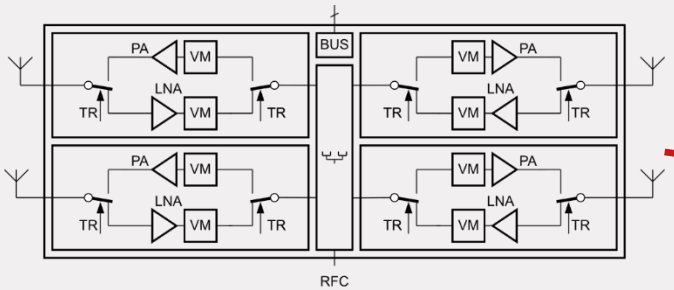


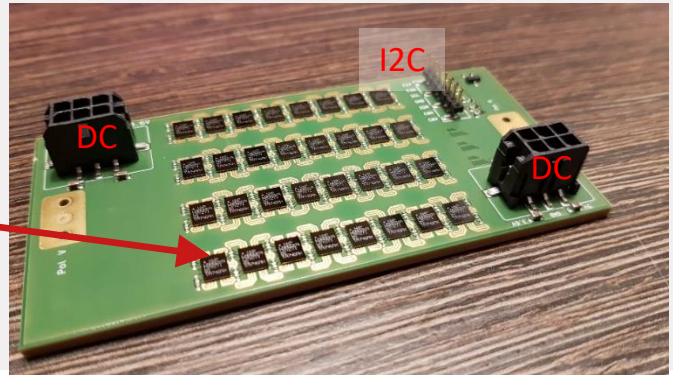
A.J. van den Biggelaar: Ongoing research

Outcome of this Design Example









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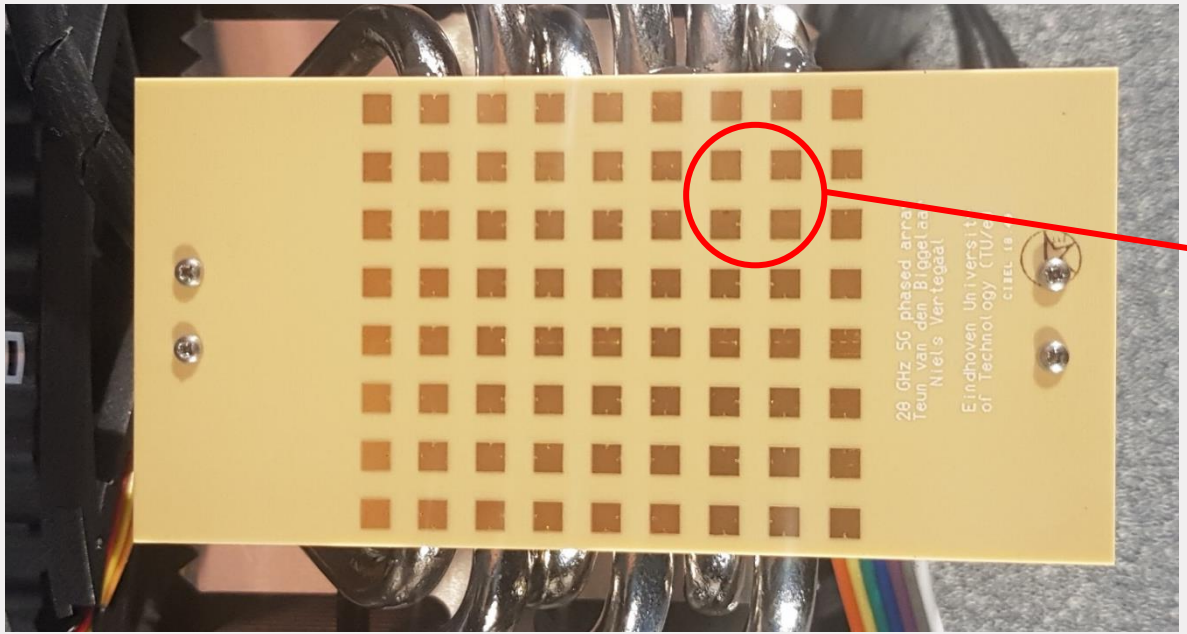

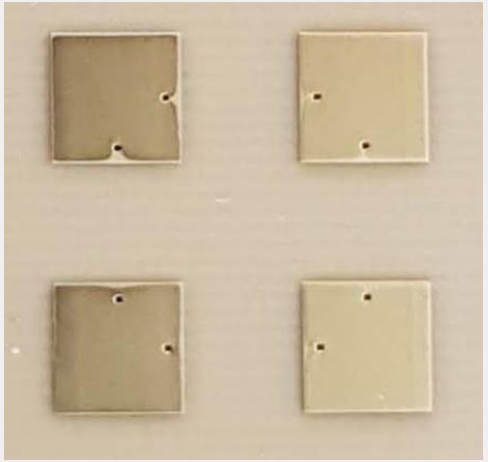

Applying SE Practices to mm-Wave Antenna System Development

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System Design: “The Fun Stuff”

Technology Choice

Scaling up the Array Size

Design Review

Validation: Antenna System Characterisation

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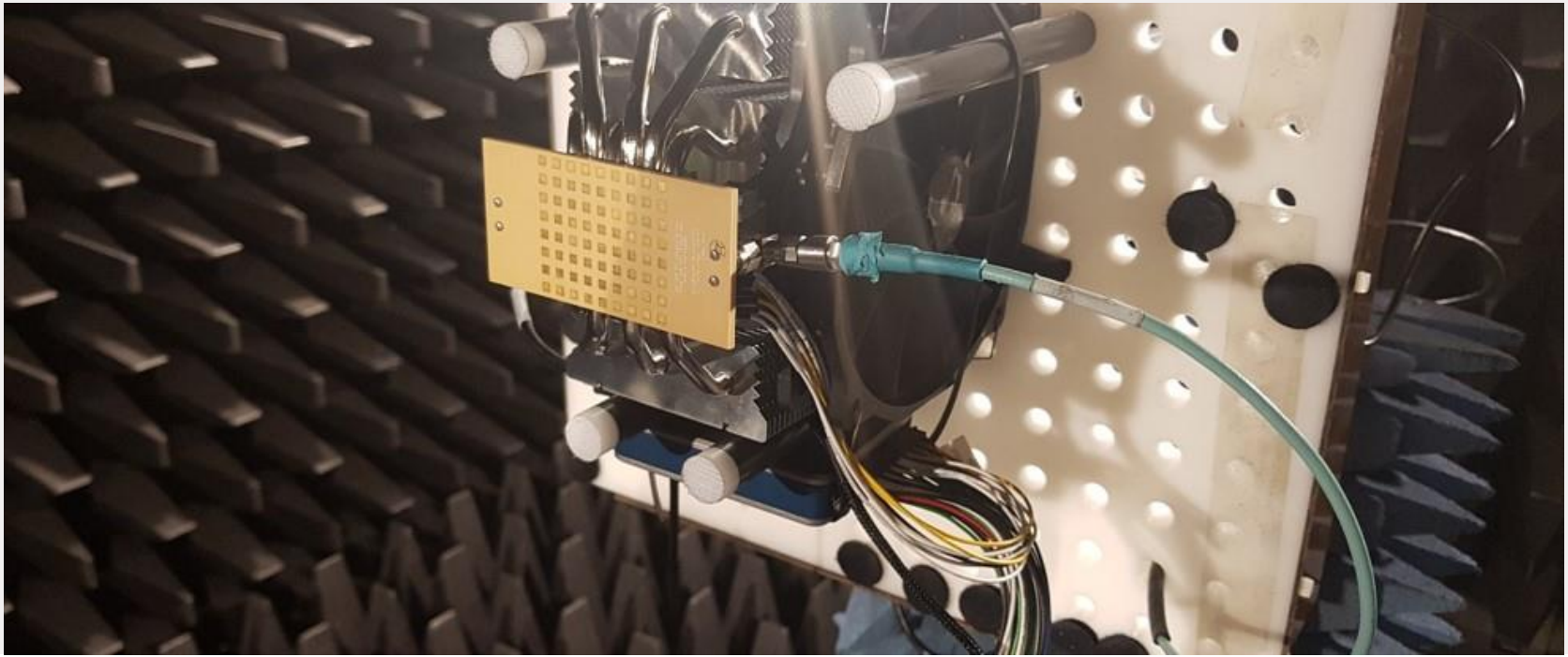
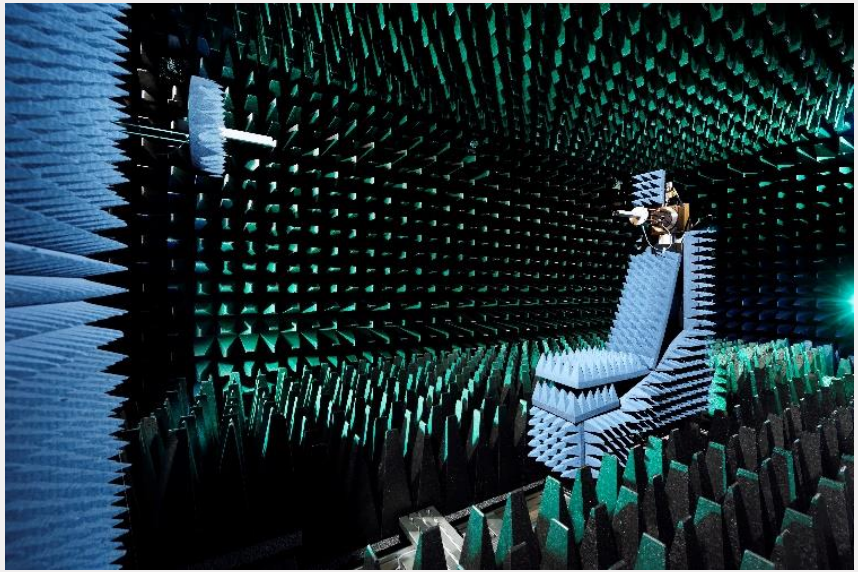
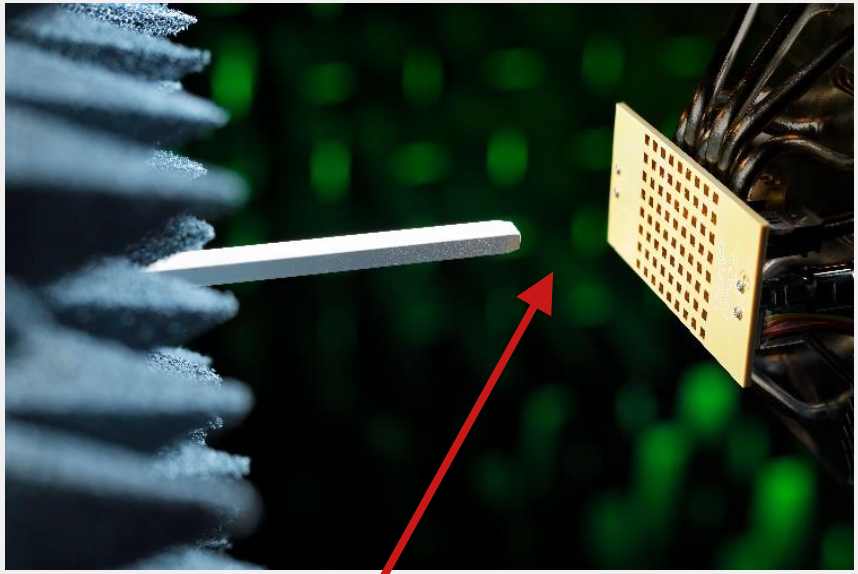
Prototype inside Anechoic Chamber



Far-Field vs Near-Field Measurements





Radiating near-field

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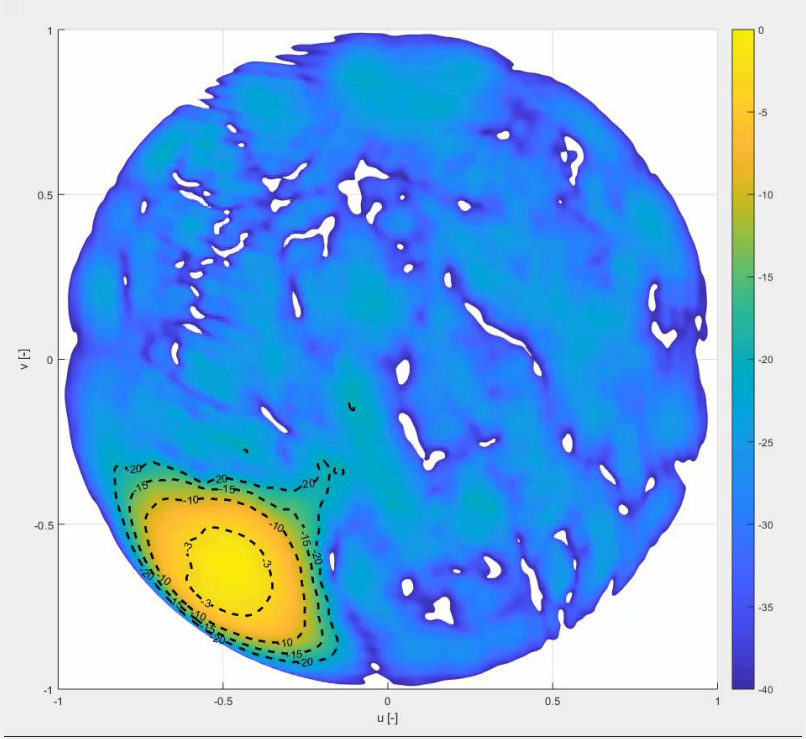
Measured Radiation Patterns



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Conclusions

- Be structured
- It’s a team effort (Don’t be shy to ask/discuss)
- Know your technology/fabrication process
- Think about the measurements while designing
- Take your time
- Have fun